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Third United Nations International Conference on the Peaceful Uses of Atomic Energy

A/CONF.28/A/741
INDIA
February 1964
Original: ENGLISH

Confidential until official release during Conference

Abstract

ENERGY REQUIREMENTS AND THE ROLE OF NUCLEAR POWER

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The paper analyses some of the latest information in regard to the growth of energy demands in the world as a whole and the resources of conventional and nuclear fuels. It is found that planning will have to be made on the basis that economically exploitable conventional resources may not support demands beyond the foreseeable future and large quanta of nuclear power will be required. Some quantitative estimates are also provided. A regional analysis is then made for the various areas of the world and it is found that the so-called underdeveloped regions will have an even greater specific need for nuclear energy than other areas due to the relative shortage of conventional fuel as compared with potential demands. The new economic data relating to various types of nuclear and conventional stations is examined.

Finally a detailed examination is made of the latest situation in India with regard to conventional and nuclear power, their relative costs in the different areas of the country and the growth in power and energy demands in the country. Cost information is presented on the Tarapur Atomic Power Station and detailed cost break-down and power costs are furnished for the Rajasthan Atomic Power Station and other stations based on heavy water-type reactors to be built in India which will provide, in the main, for the first stage of the nuclear power programme. Potential developments in the costs of these reactors are also discussed. It is shown that nuclear power is now decidedly more economical in certain areas of the country as compared

with conventional thermal power based on either oil, coal transported by rail or pit-head generation plus long distance EHV transmission. The contribution of nuclear power is expected to rise from 1.2 million kilowatts of installed capacity by the end of the fourth plan (1970-71) towards a demand of 10 million kilowatts by the end of the sixth plan (1980-81), some 20 million kilowatts by 1986, and an increasing amount thereafter. (The installation rate for nuclear power is expected to be almost 400 MW per annum in the fifth plan period (1971-76) and approaching one million kilowatts per annum between 1976-81). The manner of meeting these requirements is discussed from the point of view of fuel cycles, as also the development of supporting facilities.

Third United Nations International Conference on the Peaceful Uses of Atomic Energy

A/CONF.28/A/742
SPAIN
February 1964
Original: SPANISH

Confidential until official release during Conference

Abstract

ON TWO SCHEMES FOR NUCLEAR REACTOR CALCULATIONS

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Two mathematical schemes for nuclear reactor calculations have been prepared at the Theoretical Physics and Reactor Calculations Division of the Junta de Energía Nuclear (JEN).

The tools for the first scheme are the following programs, all coded at JEN for the UNIVAC USS-90 computer:

a) ISLERO

This program solves either the P_1 or B_1 approximation to the one-dimensional, multigroup slowing down Boltzmann equation in an infinite homogeneous slab. The 54 energy groups range from 10 MeV to 0,625 eV. Few-groups constants, to a maximum of three groups, are obtained by averaging over the flux spectrum. Input data are the isotopic composition, the geometrical buckling and the self-shielding factor.

b) PROMETEO-I and II

These programs solve the Wigner-Wilkins and the Wilkins differential equations, respectively. The thermal constants are averaged over the so obtained flux spectrum. Input data are the isotopic composition, the geometrical buckling, and temperature.

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c) EDIPO-I and II

These programs solve the one dimensional, several-group diffusion equations. EDIPO-I is a few-group (-4) program, for a maximum of 20 regions and 199 mesh points. The corresponding values for EDIPO-II are, 16, 4 and 49, respectively. An interesting feature of the last program is that of allowing up-scattering in the last three groups. The conventional method of flux sinthesis has been applied to sinthesize two dimensional fluxes by combining the results of one dimensional problems. Isotopic composition in clusters follows from the thermal flux fine distribution according to the Pershagen-Carlvik approach. A generalized Selengut method has been developed by taking advantage of the possibility offered by EDIPO II of having up-scattering in the three last energy groups. In this way interference fenomena between thermal spectra can be taken into consideration.

The whole theoretical scheme has been applied to the substitution experiments carried out in Aquilon II (Saclay) and to the exponential experiments carried out at the Physics Division of JEN, as a part of the DON Project Programme a natural uranium carbide -heavy water- organic reactor system. In all calculations the resonance self-shielding factor was left free as an adjustable parameter. Four-groups diffusion theory was used throughout.

The second scheme differs from the first essentially in that the weighting functions for averaging cross sections are not the flux spectra, but the product of importance and flux spectra. As a first step, the program CAMPEADOR has been developped to be used on the USS-90 machine. This program solves the multigroup (16 groups) diffusion equations and their adjoints for a finite or infinite homogeneous medium. The condensation to a given number of groups (16) takes place by averaging cross sections as said above. EDIPO-I and II are then used for reactivity and neutron flux distribution alculations. The schme been checked against experimental and theoretical results for fast neutron systems as given in the literature.

Third United Nations International Conference on the Peaceful Uses of Atomic Energy

A/CONF.28/A/743
SPAIN
February 1964
Original: SPANISH

Confidential until official release during Conference

Abstract

EXPERIMENTAL STUDIES OF URANIUM CARBIDE-HEAVY WATER LATTICES

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Natural uranium carbide fuelled haavy water moderated (organic cooled) lattices have been studied at the Laboratories of Junta de Energía Nuclear (J.E.N.).

The experimental device is made up of an aluminium vessel of about 2 m diameter and 2 m height with an leakage-proof top cover. The flux distribution measurements can be made at different pitches at the exhagonal lattice. A graphite thermal column with five 10 curies Sb-Be neutron sources provides an adequate neutron intensity. The measurements have been varried out at 8,5 9,5 and 10,5 inches. The UC fuel elements used are similar to those of a possible organic cooled power reactor. The results have been compared with measurement carried out with UO_2 fuel element.

Another series of measurements, with a progressibe substitution technique, have been done in colaboration with the Centre d'

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Etudes Nucleaires de Saclay in the critical facility AQUILON II. Dificulties in the interpretation of results forced a modification of the fuel elements. Two series of measurements were carried out: 1st) fuel elements without organic coolant, 2nd) fuel elements with organic coolant but without pressure and vacuum tubes. The first provides information on the UC and the second outle hidrogenous coolant influence upon the reactivity. Because of the limited length of the fuel elements it was necessary, in some of the measurements, to account for a heavy water top reflector effect.

In addition to the intrinsic information provided by these measurements, they have been used to check an theoretical scheme of calculation.

Third United Nations International Conference on the Peaceful Uses of Atomic Energy

A/CONF.28/A/744
INDIA
February 1964
Original: ENGLISH

Confidential until official release during Conference

Abstract

UTILIZATION OF RESEARCH REACTORS AT TROMBAY

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The Atomic Energy Establishment at Trombay has 3 operating research reactors: "Apsara" (1 MW) date of criticality - August 1956, "Canada-India Reactor" (40 MW) date of criticality - January 1961, "Zerlina" (zero energy reactor for lattice investigations and new assemblies) date of criticality - January 1961. These research reactors have now been working at their full capacity for the past few years and have been utilised for research in nuclear physics, solid state physics, nuclear chemistry, radiation damage chemistry and activation analysis. A brief description of the utilisation of the first two reactors for studies in fission physics and chemistry, lattice dynamics, magnetic structure and crystallography and neutron thermalisation is given. These reactors have also been used for studies in radiation damage, particularly to organic coolants. Other uses have been for the production of short-lived isotopes for studies in nuclear spectroscopy. Work done using the Zerlina reactor for the study of lattice investigations using rod clusters etc. is also described.

Third United Nations International Conference on the Peaceful Uses of Atomic Energy

A/CONF.28/A/745
INDIA
February 1964
Original: ENGLISH

Confidential until official release during Conference

Abstract

TARAPUR ATOMIC POWER STATION

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This paper gives an account of the Tarapur Atomic Power Project. The station is located about 62 miles north of Bombay and will feed power into the power systems of Western India serving industrial areas around Bombay and in Gujarat. The reasons for adopting the dual reactor design and the choice of the output of the station are dealt with. The choice of the reactor type and the constructor was made from amongst seven proposals received from four countries submitted in response to a global invitation to bid which included detailed performance requirements and also standards for design and workmanship. The station will consist of two boiling water reactors using forced circulation with internal steam separation and pressure suppression containment is adopted. The paper discusses the philosophy of the layout and the basis of design of the systems and components and how this has been influenced by conditions at the site, characteristics of the power system into which the station will be feeding power and the fact that two identical reactors are housed together. The paper also deals with the conservatism in design and the potential for exploiting this conservatism. The reasons that led to the choice of the core design which consists of slightly enriched uranium oxide pellets clad in Zircaloy-2 arranged in a 6 x 6 matrix is dealt with. Information about the cost of the station and power costs is also presented.

Third United Nations International Conference on the Peaceful Uses of Atomic Energy

A/CONF.28/A/746
INDIA
February 1964
Original: ENGLISH

Confidential until official release during Conference

Abstract

TARAPUR ATOMIC POWER PROJECT

THE INTEGRATION OF NUCLEAR POWER STATIONS IN POWER NETWORKS WITH SPECIAL REFERENCE TO THE DEVELOPING COUNTRIES

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M. Dayal, Senior Design Engineer

The introduction of nuclear power stations into power systems raises a number of problems of a technical and economic nature which have important bearings on the economy of the networks, their growth and the distribution of hydro, thermal and nuclear capacity with reference to present and future conditions. The paper discusses the various factors that have to be taken into account in deciding the role of atomic power in a power system such as size of system and units, availability factor, system load factor, storage hydro availability, operating costs, etc. The general problem of operating nuclear power stations in a power system consisting of hydro, thermal and nuclear stations is considered. The installation of sequences of nuclear and conventional power stations, and the economics of the system as a whole, are examined; the relative roles of various types of stations in meeting the load and energy requirements, both present and future, are investigated. The applicability of these methods of examination to the special problems of developing countries is examined.

The costs of nuclear and conventional stations in India are examined from the system point of view and cost comparisons between sequences of nuclear and conventional power stations discussed. Three specific power systems in India are considered in detail. These are the Western regional system, the Northern system and the Southern regional system. In these areas nuclear power stations aggregating 1.2 million kilowatts are to be installed by 1971. Examination reveals that these nuclear stations and others to be built thereafter could take the future base load in these regions and also part of the energy requirements at lower plant factors and

that maximum economies would be achieved for the systems by the installation of progressively increasing amounts of nuclear power. The paper evolves and formulates criteria which can be used, particularly by the developing countries in studying the introduction and the future role of nuclear power in power networks.

Third United Nations International Conference on the Peaceful Uses of Atomic Energy

A/CONF.28/A/747
TURKEY
February 1964
Submitted in:
ENGLISH and FRENCH

Confidential until official release during Conference

Abstract

The Programs for Utilization of the Research Reactor TR-I at the Çekmece Nuclear Center

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The TR-I (Turkish Reactor I) is a research facility located on the grounds of the Çekmece Nuclear Research and Training Center, 30 km west of Istanbul. The Center is owned and operated by the Turkish Atomic Energy Commission whose chairman is the Minister of Energy and Natural Resources. The pool type reactor has a maximum power of I Megawatt; it uses 90% enriched Uranium. The reactor and its building was constructed by the U.S. AMF Co. The first criticality was achieved on 6th of January 1962.

The experimental facilities of the reactor consist of a horizontal thermal column, 6 beam tubes of different cross sectional area, one through tube, a spent-fuel dry-gamma irradiation room, a small hot cell accessible from the pool.

The programs of utilization of the TR-I are based on the fact of its being the only facility of its kind in the country. The main task of the Çekmece Nuclear Center is the use of TR-I for research, training and

irradiations in the fields of Physics, Chemistry, Biology, Reactor Technology, Agriculture and Medicine.

The progress of programs in these fields, the organization of the Center, its collaborations with the country's universities and foreign laboratories will be explained. The significance of a Research Reactor Facility for a developing country and the policies adopted in operating the Center and the TR-I will briefly be discussed.

A/CONF.28/A/748

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Third United Nations International Conference on the Peaceful Uses of Atomic Energy

A/CONF.28/A/748
NORWAY
February 1964
Original: ENGLISH

Confidential until official release during Conference

Abstract

ON THE DYNAMIC BEHAVIOUR OF BOILING WATER SHIP REACTORS

by

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Boiling water reactors with natural circulation are inherently simple, and this type is economically attractive for small size, nuclear power plants. Such reactors are, however, particularly sensitive to accelerational disturbances, and, in the past, have been discarded for ship propulsion use.

This paper gives some results from a comprehensive study of the dynamic characteristics of boiling water reactors for marine use, with special attention to the applicability of natural circulation.

It is shown that large nuclear power transients can certainly be expected, but the resulting variations in fuel temperature, heat flow to coolant, reactor pressure, and steam flow to turbine are all within tolerable limits. It is concluded that although the nuclear power transients will inconvenience the designers of control systems, a natural circulation system can be operated reliably and safely at full power even under adverse sea conditions. Further, relatively simple means exist for improving the dynamic performance.

The paper gives a brief description of the theoretical reactor model used for the study, and some new features of the model are pointed out. A linearized version of the model was programmed for an analogue computer, which was used for most of the calculations carried out. A somewhat simplified, non-linear

model, has been programmed for a digital computer, and also used in the study.

Considerable effort has been put into the testing of the model against experimental data from reactors and boiling loops. This work will be reviewed, with emphasis on the use of data from a boiling loop in vertical motion at the Institutt for Atomenergi, as data of this type have not been readily available in the past.

Next, several examples of reactor responses to different disturbances will be presented. Dynamic design limitations will be discussed, and it is attempted to arrive at relevant design criteria for natural circulation boiling water ship reactors. At a cost, certain parameters can be chosen to optimize the reactor system from the dynamic point of view.

Third United Nations International Conference on the Peaceful Uses of Atomic Energy

A/CONF.28/A/749
INDIA
February 1964
Original: ENGLISH

Confidential until official release during Conference

Abstract

STUDY OF THE HIGH TEMPERATURE BEHAVIOUR OF URANIUM OXIDES AND OF THE KINETICS AND MECHANISM OF FORMATION OF URANIA-THORIA SOLID SOLUTIONS

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The paper summarises the results of studies on the high temperature chemistry of the oxides in the system UO_2-ThO_2-O_2 with special reference to the kinetics and mechanism of formation of solid solutions. It is shown that the mechanism by which U_3O_8 reacts with ThO_2 in air at temperatures $\geqslant 1000^{\circ}C$ to form a solid solution involves a gas phase. The importance of this gas phase reaction in fabricating high density fuels is discussed. On the basis of a study of similar reactions with other oxides (Al_2O_3, SiO_2, CaO, HfO_2, ZrO_2 and stabilized ZrO_2), it is shown that the reaction involving gaseous UO_3 proceeds only if the substrate material on which it condenses has a cubic symmetry. Thus, no reaction is observed with non-cubic oxides [Al_2O_3, SiO_2, ZrO_2(below about $1250^{\circ}C$)], noticeable reactions with the high temperature pseudo-cubic modifications, and strong reactions with cubic oxides.

For elucidating the kinetics of U_3O_8-ThO_2 reactions, the high temperature behaviour and kinetics of weight loss from nuclear pure U_3O_8 have been studied in the temperature range 1200-1500°C. The isothermal weight loss from U_3O_8 heated in air is found to vary linearly with exposed surface area and to follow a first order kinetics with an energy of activation of 104 kcal/mole and an entropy of activation of 30.5 e.u. In U_3O_8-ThO_2 mixtures there is a very sudden initial weight loss. The period over which this weight loss occurs increases with decreasing temperature. The end of this period corresponds with about 80% solid solution formation, after which the isothermal weight loss obeys first order kinetics with an energy of activation of 74 kcal/mole and an entropy of activation of 16.5 e.u. (values for 50 mole % mixture). The volatilizing species is a pure uranium oxide. This volatility of urania-thoria is discussed from the point of view of stability of such fuels at high temperatures.

The kinetics of solid solution formation obeys Jander's equation. Arrhenius plot gives an energy and entropy of activation of 41.5 kcal/mole and 6.3 e.u. respectively.

During the high temperature studies of U_3O_8 it is observed that on extremely slow cooling (100°/day) from temperatures greater than 1100°, a different phase of U_3O_8 appears. The structural relationship of this phase with the Rundle phase, and α-U_3O_8 are discussed in terms of the "out-of-step" stacking faults.

Third United Nations International Conference on the Peaceful Uses of Atomic Energy

A/CONF.28/A/750
INDIA
February 1964
Original: ENGLISH

Confidential until official release during Conference

Abstract

RELATION BETWEEN THE ORIGIN, POWDER CHARACTERISTICS AND SINTERING TREATMENTS ON THE DENSIFICATION AND MICROSTRUCTURES OF COMPACTS OF URANIA AND THORIA

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The relations between the origin, powder characteristics and sintering treatments on the densification and microstructure of compacts of (1) urania and (2) thoria have been studied. The oxide powders were prepared by thermal decomposition of uranyl and thorium compounds viz. tannate, benzoate, oxalate etc. The microstructure of a sintered compact influences some of its physical properties such as thermal conductivity and fission gas retention and as such is an important factor responsible for the difference in performance of pellets of the same density during service in a reactor.

The oxide powders derived from the various compounds showed significant differences in their crystallite size; oxide powders from the same compound, calcined at higher temperatures had an increased crystallite size and lowered surface area. In this study, UO_2 sintering was carried out in hydrogen and ThO_2 sintering in air. In both the cases, powders with smaller crystallite size started densification at a lower temperature and attained high densities at significantly low temperatures (1200 - 1300°C), other conditions of sintering treatment being the same. There was an optimum temperature for each of the powders, to attain the maximum densification.

The influence of the period of soak at the sintering temperature on

the densification of these powder compacts was studied. At certain time intervals, specific for the powder and the sintering temperature, significant lowering in densification was noticed. The extent of drop in density, and the time of its occurrence at each of the sintering temperatures were related to the origin and characteristics of the powder used.

The study of the microstructures revealed that the changes in densification were due to the formation of closed porosity during the heating period and its subsequent enhancement during the sintering treatment. Grain development depended to a larger extent on the temperature than on the sintered density attained. Minor impurities, atmospheres of sintering etc. also exert an influence on the densification and grain growth, e.g. traces of titania in urania promote both densification and grain growth at lower temperature ($\simeq$1100°C).

Thus, the sintering characteristics of urania and thoria powders depend on the origin and powder characteristics (including presence of minor impurities). To prepare sintered compacts approaching theoretical density, from any given powder, the sintering conditions should be so chosen as to avoid the formation of closed porosity. The sintering temperature could be maintained sufficiently low without any appreciable grain growth taking place, even though a density over 95% theoretical is attained. Grain growth, if desired, can be obtained by a subsequent heat treatment.

Third United Nations International Conference on the Peaceful Uses of Atomic Energy

A/CONF.28/A/751
INDIA
February 1964
Original: ENGLISH

Confidential until official release during Conference

Abstract

FABRICATION OF URANIUM OXIDE FUEL ELEMENTS AT TROMBAY

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Uranium oxide is being increasingly used as a fuel, especially in power reactors, on account of its superior properties, chief among them being corrosion resistance and stability under irradiation leading to high burn up. A 19-rod cluster type of fuel element has been favoured for the proposed prototype power reactor NUHMOC from considerations of high specific power. The present fuel elements were fabricated for studying the physics parameters in the zero energy reactor, ZERLINA.

The paper is concerned with the fabrication of the 19-rod fuel clusters starting from the production of ceramic grade uranium oxide powder. The uranium oxide has been prepared under different conditions, using gaseous or liquor ammonia or other

reagents for precipitation, and by varying the conditions of calcination and reduction. The conditioning of the powder to minimise its pyrophoric tendency and to achieve a desirable O/U ratio has been studied. The effect of the physical characteristics of the powder such as particle size, specific surface, bulk and tap densities on the ultimate sintered densities has been investigated.

The various steps involved in the fabrication of the uranium oxide pellets such as granulation, blending, compacting, dewaxing, and sintering have been dealt with. The effect of die taper in die design, pressing conditions, the effect of various atmospheres, such as vacuum, carbon dioxide and nitrogen, during dewaxing have been studied. Similarly the conditions of sintering have been varied to achieve high sintered densities at as low a sintering temperature as possible.

The sintered pellets are centreless and surface ground prior to assembly and these aspects have been briefly discussed. The assembly of the machined uranium oxide pellets into 1S-aluminium tubes (14.4 mm i.d., 0.7 mm wall thickness and 2429 mm long), the end-closure by argon arc fusion welding, and their assembly into 19-rod clusters are described. A complete charge of the fuel loading for test purposes on Zerlina will be ready by the middle of 1964.

Third United Nations International Conference on the Peaceful Uses of Atomic Energy

A/CONF.28/A/752
INDIA
February 1964
Original: ENGLISH

Confidential until official release during Conference

Abstract

A REVIEW OF URANIUM AND THORIUM DEPOSITS OF INDIA

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The Atomic Minerals Division of the Indian Atomic Energy Commission are engaged in a systematic nation-wide search for radioactive minerals. A number of uranium deposits have been located in the Pre-Cambrian rocks in different parts of the country.

The most important deposits are in the Archaean metasediments, in the generally east-west trending 140-kilometer long Singhbhum Thrust Belt in South Bihar (Eastern India), where the older Chaibasa and Iron Ore stages are thrust over the younger Dhanjori rocks.

Commercial deposits are confined to certain localities and appear to have been controlled partly by structure and by the physico-chemical characters of rocks, the siliceous-chlorite-schists, biotite-schists and quartzite-breccia being the most favoured hosts.

Exploratory core drilling aggregating some 65,000 meters in the belt has enabled underground development to be undertaken at Keruadungri, Marwapahar and Bhatin while at Jaduguda full scale mining operations have been launched for feeding the uranium mill. The ore potential of the belt is estimated at about 20-million tonnes of 0.05 - 0.07 percent eU_3O_8 grade. Further investigations which are underway are likely to augment the ore reserves making this belt the principal source of

uranium in India.

Pre-Cambrian rocks in Rajasthan also contain a few sporadic and smaller deposits. Recently promising indications of uranium have been discovered in the Pre-Cambrian of Kulu and early Palaeozoic of Garhwal in Central Himalayas. In all these cases, the deposits are associated more with copper than with lead, zinc or gold. The mineralisation is epigenetic and brought about by the hydrothermal action of fluids derived from high alkali magmas.

Most of the Indian granites and gneisses are radioactive due to disseminated uranium and/or thorium, chiefly the latter. Secondary uranyl minerals autunite, uranophane, bayleyite etc., occur in granites. Most pegmatites contain sporadic pockets of uranium and thorium minerals. Brecciated rhyolites with felsite intrusions occasionally show uranium mineralisation.

Except for insignificant amount of uranium, the terrestrial Gondwana sediments and some Tertiary coals and lignites, sedimentary rocks in India are devoid of uranium.

Thorium deposits are widely scattered. Monazite, the main thorium mineral which is derived from the granites and gneisses of the Peninsular Shield is concentrated along the Western and Eastern sea-board of India. There are some rich inland placers and the Jurassic sandstones of Cutch and Kathiawar which carry monazite.

Indian reserves of uranium (U_3O_8) and thorium (ThO_2) are estimated at about 30,000 tonnes and 0.5 million tonnes respectively, the latter being one of the largest in the world.

Third United Nations International Conference on the Peaceful Uses of Atomic Energy

A/CONF.28/A/753
INDIA
February 1964
Original: ENGLISH

Confidential until official release during Conference

Abstract

TECHNICAL AND ECONOMIC CONSIDERATIONS FOR PRODUCING 200 T/YEAR OF HEAVY WATER IN INDIA

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Atomic Energy Establishment Trombay

This paper discusses the technical and economic considerations for producing 200 t/year of heavy water in India utilising middling coal as the principal source of heat to the system by locating the plant near a coal mine or a coal washery. The process to be adopted for this plant consists of the H_2S-H_2O dual temp. exchange for pre-enrichment, followed by water distillation for the final enrichment to reactor grade heavy water. Since the cost of energy forms a major part of the operating cost of this process, a location near a cheap fuel source has an important bearing on production costs.

The cost involved in expanding the present heavy water plant (14 t/year) at Nangal to produce 200 t/year by pre-enrichment of the feed to the electrolysers by an H_2S-H_2O exchange process and providing additional capacity in the final enrichment step of hydrogen distillation has been worked out.

A comparison of the operating cost for these two plants show that the plant near a coal mine or a coal washery will produce heavy water at a lower cost.

Third United Nations International Conference on the Peaceful Uses of Atomic Energy

A/CONF.28/A/754
INDIA
February 1964
Original: ENGLISH

Confidential until official release during Conference

Abstract

ANALYSIS OF OPERATING EXPERIENCE OF A HYDROGEN DISTILLATION PLANT

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Atomic Energy Establishment Trombay

A hydrogen distillation plant for the production of heavy water has been operating at Nangal since August 1962. The main problems encountered during the initial commissioning and subsequent operations have been described. Power consumption, refrigeration requirements, gas losses and column efficiencies have been analysed and compared with available literature.

On the basis of data obtained and the present experience of operating a heavy water plant, it is considered that lower production costs can be achieved if hydrogen distillation is carried out under vacuum. Various problems likely to be encountered, their suggested solutions along with process design and estimated operating costs of a new plant are presented in the paper.

Third United Nations International Conference on the Peaceful Uses of Atomic Energy

A/CONF.28/A/755
ISRAEL

February 1964

Submitted in:
ENGLISH and FRENCH

Confidential until official release during Conference

Abstract

MISCIBILITY GAP IN EXTRACTION SYSTEMS INVOLVING ALKYLAMINES

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The formation of a third phase, a second organic one, is frequent in solvent extraction processes involving long-chain amines and aliphatic hydrocarbons as diluents. Quaternary systems (tertiary amine-diluent-water-hydrochloric acid) and quintanary systems, involving uranyl chloride, have been studied.

When solutions of amines in aliphatic hydrocarbons are equilibrated with equal volumes of aqueous hydrochloric acid of increasing concentration, there is a lower critical acid concentration at which the equilibrium organic phase splits into two, thus forming a third phase, and an upper critical acid concentration, which causes the third phase to disappear or prevents its formation. The "miscibility-immiscibility" of the two organic phases in equilibrium is reversible.

This phenomenon of a miscibility gap in a two-phase conjugate system is apparently unrelated to the dielectric constant or the dipole moment of the diluent, since in aromatic hydrocarbons the organic phase remains throughout homogeneous. Estimates based on the solubility parameter concept and expressed in terms of the Flory-Huggins entropy of mixing equation permitted quantitative differentiation between the aliphatic and aromatic hydrocarbon diluents, but failed to explain the differences observed among different aliphatic hydrocarbons. Calculations based on the molar polarizabilities, P_{12}, of the amine-diluent mixtures and expressed in terms of the Clausius-Mossotti equation, show a correlation between polarizability and miscibility, immiscibility being favoured by higher P_{12}.

Examination of the growth and diminution of the third phase in the system trinonylamine-hexane as a function of acid concentration, of the composition of the phases in equilibrium, and of their conductance, indicated that the third phase formation is accompanied by a chemical reaction leading to the formation of charged species.

An excess of HCl over and above the amount needed for the formation of the amine hydrochloride produces the splitting of the homogeneous organic phase; when the amount of acid transferred from the aqueous phase equals twice the total amine concentration, the organic phase becomes homogeneous again. The amine hydrogen dichloride is formed when the acid/amine ratio is higher than unity. The dichloride ion cannot be free but must exist in the organic solution in a tight ion-pair with the proton. The conductometric measurements suggest that indeed both the amine hydrochloride and the amine hydrogen dichloride are poorly conducting species, whereas charged species exist in the organic phase throughout the acidity range in which the miscibility gap exists. It is suggested that these charged species are formed through association of a single ion with the dipole of an ion-pair and are intermediate to the formation of amine hydrogen dichloride quadrupoles.

In aromatic hydrocarbons the amine hydrochloride is a solvent-shared or solvent-separated ion-pair, as distinguished from the state of the solute in the ideally non-solvating aliphatic hydrocarbons.